DEPARTMENT OF COMMERCE

TECHNOLOGIC PAPERS
OF THE
BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 127

LEAKAGE RESISTANCE OF STREET RAILWAY ROADBEDS AND ITS RELATION TO ELECTROLYSIS OF UNDERGROUND STRUCTURES

BY

E. R. SHEPARD, Electrical Engineer
Bureau of Standards
IN COLLABORATION WITH THE
U. S. Forest Products Laboratory
Forest Service, U. S. Department of Agriculture
at Madison, Wis.

ISSUED OCTOBER 6, 1919

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By E. R. Shepard

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I. INTRODUCTION

Although much attention has been given to the subject of electrolysis mitigation and many methods have been proposed and used for preventing and reducing the escape of electricity from street-railway tracks used as the return circuit, it seems that very little thought has been given by street-railway engineers to the question of insulating such roadbeds or constructing them in such a manner as to offer high resistance to leakage currents.

In the 1914 report of the committee on way matters to the American Electric Railway Engineering Association, "Effect on Electrolysis" was ennumerated as one of the 12 factors influencing the design for "Proper Foundation for Tracks in Paved Streets," but it does not appear that this factor was considered by the committee in recommending 4 standard types of construction, nor is any mention of this subject found in the discussion following the report of the committee, although the 4 types of foundations differ greatly in their electrical resistance to leakage currents. The cause for an apparent lack of consideration of this factor is probably due, not to a disinterest in the subject, but rather to the absence of information on which conclusions could be based and to a greater interest in other factors, considered of prime importance in the construction of electric railways.

Practically no data on the resistance of different types of roadbeds are available, although the relative resistance of some types are known in a general way. For instance, open-track construction on gravel or stone ballast, with rails out of contact with the earth, is generally known to have a high resistance to earth, and this kind of construction is frequently considered as a complete and sufficient protection to adjacent pipes and other underground structures. On the other hand, track construction without ballast and with rails in contact with earth, and particularly wet earth, is known to afford a low-resistance path to leakage currents. It is well known that roadbeds having ties treated with zinc chloride and other chemicals offer low resistance between rails and earth as well as between the two rails in a block. Signal engineers have frequently traced false signals to this cause.

Some few investigations have been made of the resistivity of different kinds of wood with varying moisture content and with different preservative treatments, but such data are of little value in determining the composite leakage resistance of a roadbed. Ahlborn,[1] in 1911 and 1913, made measurements on three electric lines, each being several miles in length, and calculated the average leakage resistance for each line by a somewhat indirect method. His results show wide differences in the resistances of different kinds of roadbeds and emphasize the need of further investigation of this subject. He found an open track on high, well-drained, gravelly soil to have a leakage resistance of 14.57 ohms for each 1000 feet of single track, while a similar track on low, marshy clay and gravel, with the rails in contact with the earth in many places, had a leakage resistance of only 1.76 ohms for each 1000 feet of single track. A city track in Washington on crushed-rock ballast with a "Tarvia" surface, was found to have a leakage resistance of 1.81 ohms for each 1000 feet of double track or about twice the resistance of the second line. Only three lines were investigated and each under a single condition of the soil.

The object of this paper is to present leakage-resistance data on a number of types of roadbeds for different weather and soil conditions and to discuss the several factors which influence the resistance of roadbeds. With such information available to the street-railway engineers, they will be able to give this subject the attention which it deserves and to select those types of construction which, consistent with other features, give the highest leakage resistance, and therefore the best electrolysis conditions.

II. PRINCIPLES AND DEFINITIONS

The leakage path traversed by stray currents from electric railways consists of several elements and varies greatly with different types of roadbed construction. In the case of open track, the current leaves the rails, entering the ties through the spikes and the base of the rails, and then passes into the ballast and finally into the adjacent earth from which part of it finds its way to metallic structures, and eventually to the negative pole of the generator. In paved streets an additional leakage path is offered through direct contact of the rails with the earth, pavement, or other material in which they are embedded.

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[1] G. H. Ahlborn, "Data on Electric Railway Track Leakage," Technologic Papers of the Bureau of Standards, No. 75.

In this paper the part of the circuit in which we are concerned is termed "the roadbed" and consists of the pavement, ties, and ballast. By far the greatest part of the total resistance of the leakage path is to be found in the roadbed, particularly in open construction, where the wood ties almost act as insulators between the rails and the earth. In the case of earth ballast or where the ties are laid on a natural gravel ballast, the extent of the roadbed is, of course, indefinite. In determining the resistance of any types of roadbed, an attempt was made to measure the resistance between the rails and a remote ground, such as a network of water mains. Such a measurement would, of course, include the resistance of the earth between the roadbed and the remote ground, but as this is only a very small fraction of the total resistance where ordinary types of construction are involved, it is here included in the roadbed resistance.

The difficulties involved in making roadbed-resistance measurements on ordinary track systems are at once evident when one considers that in general such systems are electrically continuous for miles and include many different types of construction. Moreover, they are actively employed for 18, and in many places 24, hours each day, during which time accurate electrical measurements would be impossible. In order, therefore, to determine the resistance to earth of any limited section of track, it is necessary to either isolate that section from the remainder of the track network or else make careful differential measurements at a time when no cars are in operation. Both of these methods require the work to be done at night on tracks not employed for "owl service."

In the District of Columbia, where this investigation was carried out, another restriction is imposed by the double underground trolley system which is used exclusively except on some of the suburban lines. Where this system is employed the rail joints are not bonded and resistance measurements therefore could not be made. In view of these various conditions it was found that only three types of open track and two types of city track in the District were suitable for the desired measurements.

In order to supplement the information which could be obtained on the city tracks several short sections of experimental roadbeds of different types were constructed on the grounds of the Bureau, and these offered an opportunity of observing the effects of different weather and soil conditions as well as permitting experimentation with new types and modifications and variations of standard types.

III. MEASUREMENTS ON CITY AND SUBURBAN ROADBEDS

1. DIFFERENTIAL METHOD OF MEASURING ROADBED RESISTANCE

Fig. 1 illustrates the method employed for making measurements on roadbeds where it was found impracticable to isolate a limited section of the track. After the car traffic has been withdrawn for the night, a portable storage battery is connected, as shown, between the four rails of the track and a water hydrant on a relatively large main. An ammeter and a regulating resistance are included in the circuit. Nine Edison storage cells were employed for this purpose and a constant current of from 25 to 35 amperes was maintained during the period of the test. The current entering the rails will flow away from the test station in both directions, as shown by the arrows. Leakage will take place to the earth and all of the current will be picked up by the water-piping system and returned to the negative pole of the battery. If now a millivoltmeter be employed to measure the potential drop on a short section of the track at Station A and again at several thousand feet distant at Station B, the loss of current from the rails between the two stations can at once be determined, provided the rails are of the same weight and resistivity at the two stations, and provided further, that the battery current has remained constant. Now, if the potential difference between the

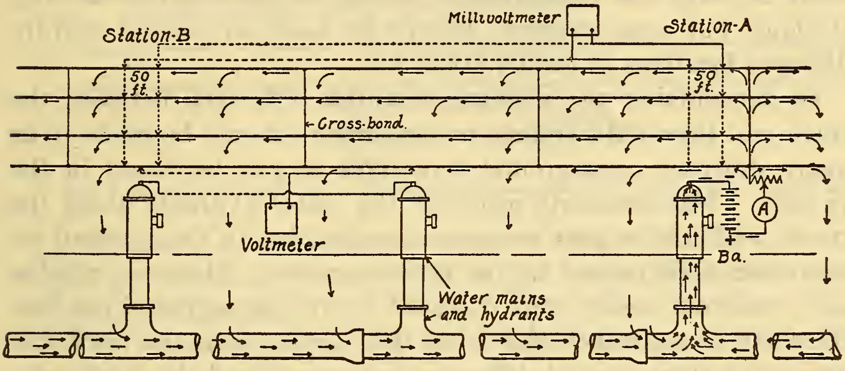


FIG. 1.—*Differential method of making roadbed resistance measurements*

section of track under test and the earth at some distance from it be measured, the resistance to earth of this section of track can be easily computed.

While the principle involved in such a measurement is extremely simple, the practical difficulties encountered make accurate and reliable results very difficult of attainment, and it is only by many and repeated measurements that reliable data can be secured. The difference between the currents at Stations A and B is the quantity which must be determined, and as this is usually a small fraction of the total current, even over a distance of one-half mile, a slight error in the measurements would be exaggerated in the result. Errors might result from inaccurate readings or from different rail weights or resistivities. It is necessary, therefore, to make not only one measurement on each of the four rails at both stations, but measurements should be made at several slightly different locations at each station.

In determining the average potential difference between the track and the earth, voltage measurements should be made to as many different underground structures as can be found in the vicinity. Measurements made to the water hydrants along the track are likely to give erroneous results, due to the gradient on the water main caused by the return current. The most reliable and consistent results were obtained by driving a ground rod into the earth at a distance of not less than 50 feet from the track and measuring the potential difference between it and the track with a high resistance voltmeter.

This differential method was employed on the Wisconsin Avenue line in Washington at two different locations, designated as (a) and (b) in Table 1, and on the Chevy Chase line in three different locations, designated as (c), (d), and (e) in Table 1. The measurements extended over a period of two years and were taken under different moisture conditions of the roadbed.

2. ISOLATION METHOD OF MEASURING ROADBED RESISTANCE

Some of the suburban roadbeds on which it was desired to make measurements were in localities where no piping systems existed and where the method just described could therefore not be employed. These roadbeds were of open construction and it was therefore a comparatively simple matter to remove the joint plates and bonds from four joints, thus isolating a section of track on which accurate and reliable measurements could be made. Fig. 2 shows the arrangement of the apparatus for this test. A section of track from 100 to 500 feet in length is isolated from the remainder of the track network by removing the bonds and joint plates as shown. All cross bonds between this test section and the adjacent track must also be cut. A battery of three or four dry cells is connected between the test section and the remainder of the track network, which, being of great extent, is considered as a remote ground of negligible resistance. A low-reading ammeter and a voltmeter give the leakage current and the potential difference between the section of track under test and the remote ground, and from these data the resistance to earth is easily and accurately calculated.

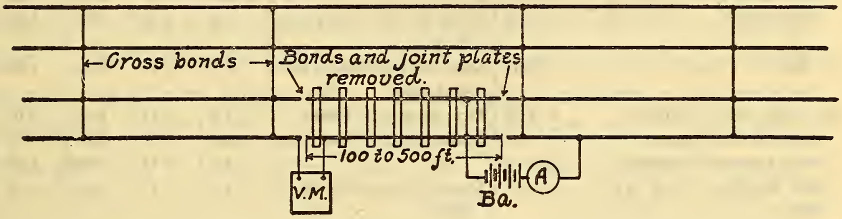


FIG. 2.—*Method of making roadbed resistance measurements on open track construction*

By taking a length of track several hundred feet in extent, the effect of the short leakage paths at the ends of the section is practically eliminated.

The resistance so found is for a single-track roadbed, but in the open type of construction the resistance to earth is concentrated largely in the ties and therefore the resistance of double track can be taken as one-half that of single track. This method of measuring roadbed resistances necessitates working at night, as does the differential method, since it usually requires several hours to remove and replace the bonds and joint plates on four joints.

Measurements by this method were made on the Cabin John line in Washington and on the Washington, Baltimore & Annapolis tracks just outside the District of Columbia.[2] These locations are designated as (f) and (g), respectively, in Table 1.

---

[2] These measurements were made possible through the courteous cooperation of C. S. Kimball, engineer, maintenance of way, Washington Railway & Electric Co., and E. W. Wemland, engineer, maintenance of way, Washington, Baltimore & Annapolis Electric Railroad Co.

TABLE 1.—Electrical Resistance of City and Suburban Roadbeds

DOUBLE TRACK

Location and kind of roadbed	Date of test	Condition of roadbed	Average potential to earth	Leakage current	Distance	Resistance of 1000 feet of track to earth
			Volts	Amprs.	Feet	Ohms
(a) Gravel ballast to head of of 70-pound T rails; much sand and earth washed in.	2–17–15	Wet	2.2	12.2	2900	0.522
	2–26–15	.....do	1.3	6.9	2900	.547
	8–14–15	.....do	1.5	7.88	2900	.552
	4– 3–17	Surface dry; ballast moist.	2.1	7.66	3300	.902
	4– 9–15	Moist	1.0	2.85	3750	1.3
(b) Same	4–17–15	Moist; no rain for 6 days	1.5	3.73	2750	1.1
(c) Crushed-rock ballast to head of 80-pound T rails; Tarvia finish.	4– 6–15	Wet	2.4	9.0	3000	.8
	8–31–15	.....do	1.8	6.67	2690	.72
	4– 5–17	Quite dry; no rain for 12 days.	3.3	6.31	3050	1.60
(d) Same	4–21–15	Quite dry; no rain for several days.	3.2	4.7	1700	1.16
(e) Open track; crushed rock to base of 80-pound T rails; frequent crossings with ballast to head of rails.	4– 2–15	Dry; no rain for weeks	3.8	3.12	4100	5.07
	4– 6–15	Surface dry; ballast wet	3.5	7.5	6500	3.03
	8–31–15	.....do	3.8	4.14	2360	2.17
	4– 5–17	Quite dry; no rain for 12 days.	4.9	2.1	1140	2.66

SINGLE TRACK

Location and kind of roadbed	Date of test	Condition of roadbed	Average potential to earth	Leakage current	Distance	Resistance of 1000 feet of track to earth
(f) Open track; cinder ballast from 4 inches below ties to base of 60-pound T rails.	10– 2–15	Surface moist; ballast wet.	6.8	0.302	361	8.2
	11–10–15	Dry; no rain for 20 days	9.8	.197	361	18.0
(g) Open track; deep gravel ballast to base of 80-pound T rails.	9–25–15	Surface dry; ballast moist.	8.2	.71	462	5.34
	11–12–15	Dry; no rain for 22 days	9.5	.615	462	7.14

3. RESULTS OF MEASUREMENTS ON CITY AND SUBURBAN ROADBEDS

In Table 1 are given the results of all measurements made in and near the District of Columbia on tracks bearing normal traffic. At locations (a), (b), (c), (d), and (e) measurements were made by the differential method previously described, and at locations (f) and (g) the isolation method was employed. Both the Wisconsin Avenue line, shown in locations (a) and (b), and the Chevy Chase line, shown in locations (c), (d), and (e), run close to the Bureau of Standards and offered the most promising conditions for investigation. The Wisconsin Avenue tracks are maintained on one side of the avenue from which vehicular traffic is excluded, except at street crossings. They were originally ballasted with gravel up to and around the base of the rails and earth was filled in to the head of the rails.

The earth has so washed into the ballast, however, as to make the roadbed more like earth than gravel as far as its electrical resistance is concerned. In many places the earth has been largely washed away and the rails are exposed nearly to the base. For the most part, however, the rails are well embedded in gravel and earth, and the roadbed can be considered as having unusually low resistance. No measurements were made on this line under extremely dry conditions. The first three tests were made with the roadbed very wet and the results obtained are quite low and agree closely. The resistance of about 0.5 ohm for 1000 feet of double track, as shown in the table, is about half of that found at the same location under drier conditions.

The Chevy Chase line is well ballasted with crushed rock and a portion of it has been paved to the head of the rails with a Tarvia finish. The tracks lie in the center of Connecticut Avenue with vehicular traffic on either side. The finish has become somewhat porous and much of the rain penetrates to the ballast. This condition prevails in locations (c) and (d). At location (e) the pavement has been omitted except at crossings. The ballast is clean, as very little earth or foreign matter has been washed into the roadbed. The street pavement on both sides of the track prevents rain from draining off and this necessarily soaks into the roadbed. The open construction, however, permits of evaporation from the ties and ballast, and as a rule this roadbed is probably drier than that portion which is paved.

The resistance of the paved portion varies from 0.72 to 1.6 ohms for 1000 feet of double track, depending upon the moisture conditions. The open construction has a much higher resistance, ranging from 2.17 to 5.07 ohms, or about four times that of the Wisconsin Avenue roadbed.

The Chevy Chase line is one which Ahlborn investigated in 1911 and for which he found an average resistance of 1.76 ohms for 1000 feet of double-track roadbed. As part of this line is open construction and part paved, a direct comparison with the figures here given is not possible although the results obtained by the two methods are seen to be in substantial agreement.

The cinder ballast and open construction of the Cabin John line offers a very high resistance to leakage currents. Two tests were made under different moisture conditions which gave 8.2 and 18.0 ohms, respectively, for 1000 feet of single track. The resistance to earth of double track would be approximately one-half of these figures.

Two measurements made under conditions similar to those existing on the cinder track were made on the Washington, Baltimore & Annapolis line, which is ballasted with gravel. It is seen that the gravel-ballasted roadbed has about one-half the resistance of the roadbed with cinder ballast. This difference can not be attributed primarily to the difference in resistivity of the two kinds of ballast. It is altogether probable, as will be shown by the results of other experiments, that the character of the ties is a most important factor in these types of construction and is probably responsible, more than the ballast, for the observed difference in the roadbed resistances.

IV. EXPERIMENTAL ROADBEDS

Owing to the difficulties involved in making resistance measurements on city tracks and the limited number of types available for such tests, it was decided to build short sections of a number of different types of roadbeds on which frequent measurements could be made. It was realized that such roadbeds might exhibit quite different characteristics from similar types subjected to the action of traffic, to the surface drainage from city streets, and to the presence of salt which is frequently used to prevent freezing. Such roadbeds would, however, permit of a careful study of the effect of moisture and temperature and would also enable comparative measurements to be made which could easily be checked by similar data obtained from city tracks under operation.

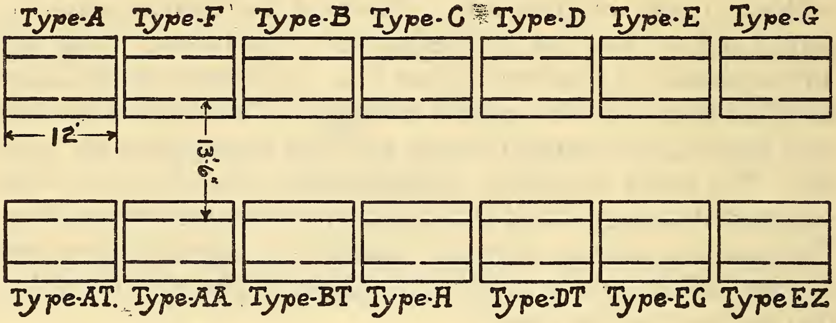


FIG. 3.—*Arrangement of experimental roadbeds*

1. DESCRIPTION OF EXPERIMENTAL ROADBEDS

Fourteen types of experimental roadbeds were built on the Bureau grounds early in 1915, and arranged as shown in Fig. 3. A detailed description of the different types follows and a condensed description is given in Table 2. Four types are illustrated in Fig. 4.

TABLE 2.—Condensed Description of Experimental Roadbeds

Type	Ballast	Ties	Rails	Surface	Special features
A	Concrete	7 by 8 inch oak, 2-foot centers.	7-inch girder	Vitrified paving brick.	
AT	do	do	do	do	Roadbed insulated with tar paper and pitch.
AA	do	do	do	do	Roadbed insulated with tar paper and asphalt.
B	do	Steel, 3-foot centers	do	do	
BT	do	do	do	do	Roadbed insulated with tar paper and pitch.
C	Crushed rock	7 by 8 inch oak, 2-foot centers.	4-inch T	Tarvia	
D	Earth to head of rails.	do	do	Earth	
DT	do	do	do	do	Rails insulated with pitch.
E	Earth to base of rails.	do	do	Open construction.	
EC	do	do	do	do	Ties treated with 10 pounds creosote per cubic foot.
EZ	do	do	do	do	Ties treated with ½ pound zinc chloride and 2 pounds creosote per cubic foot.
F	Crushed rock and concrete.	do	7-inch girder	Vitrified paving brick.	
G	Crushed stone to head of rail.	do	4-inch T	No surfacing	
H	Cinders	do	do	Open construction.	

2. TYPES OF EXPERIMENTAL ROADBED

TYPE A (See Fig. 4).—*Ballast.*—Gravel concrete, 1–4–8 mixture.

Ties.—Seven by eight inches by eight feet, oak, on 2-foot centers.

Rails.—Seven-inch, 90-pound girder, 4-inch base.

Spikes.—Six-inch, driven, four per tie.

Surface.—Vitrified paving bricks on sand cushion; 1–3 dry mix between bricks and rails; 1–3 thin grout swept into joints after laying; ¾-inch crown between rails.

TYPE AT.—Same as Type A in every respect with base insulated as follows:

Before laying the concrete a layer of roofing paper was spread over the entire roadbed and at the sides of the roadbed excavation to the street level. This paper was then covered with a mixture of 75 per cent coal-tar pitch and 25 per cent coal tar. This was applied at a temperature of about 200° F. While this coat was still hot a second layer of paper was applied and then a second coat of tar and pitch.

The paper used was a soft tar paper manufactured by the General Roofing & Manufacturing Co. and purchased as a 15-pound felt. The tar was added to the pitch to make it less brittle.

TYPE AA.—Same as Type AT in every respect, except that asphalt was used instead of tar and pitch.

TYPE B (See Fig. 4).—*Ballast.*—Gravel concrete, 1–4–8 mixture.

Ties.—Carnegie steel ties, M25, on 3-foot centers.

Rails.—Seven-inch, 90-pound girder, 4-inch base.

Clips.—No. 23 tie clips, four per tie.

Surface.—Same as for Type A.

TYPE BT.—Same as Type B with base insulated the same as in Type AT.

TYPE C (See Fig. 4).—*Ballast.*—Crushed rock from 5 inches below ties to within 2½ inches of finished surface, tamped and covered with sand.

Ties.—Seven by eight inches by eight feet, oak, on 2-foot centers.

Rails.—Four-inch T.

Spikes.—Six-inch, driven, four per tie.

Surface.—Barrett Manufacturing Co. specification as follows: Over base spread 2½ inches of crushed stone, 1 to 3 inches in size, and dry roll (tamped). Spread 1.7 gallons of Tarvia X per square yard over this at a temperature of 200 to 300° F. Cover with fine gravel, not larger than ½ inch and roll (tamped). Spread evenly ½ gallon of Tarvia X per square yard and finally cover with sand for a wearing surface.

TYPE D (EARTH ROADBED).—*Ballast.*—Earth to head of rails.

Ties.—Seven by eight inches by eight feet, oak, on 2-foot centers.

Rails.—Four-inch T.

Spikes.—Six-inch, driven, four per tie.

Surface.—Earth.

TYPE DT.—Same as Type D, with rails coated with a mixture of 75 per cent coal-tar pitch and 25 per cent coal tar to make the coating less brittle. This coating was applied hot.

TYPE E (OPEN CONSTRUCTION).—*Ballast.*—Earth to base of rails.

Ties.—Seven by eight inches by eight feet, oak, untreated, on 2-foot centers.

Rails.—Four-inch T.

Spikes.—Six-inch, driven, four per tie.

Surface.—Open construction.

TYPE EC.—Same as Type E, but with ties treated by the Baltimore & Ohio Railroad Co. by the vacuum-pressure treatment with 10 pounds of coal-tar creosote per cubic foot. Treated in October, 1914.

TYPE EZ.—Same as Type E, but with ties treated by the Baltimore & Ohio Railroad Co. by the "Card" process with ½ pound of zinc chloride and 2 pounds of coal-tar creosote per cubic foot. Treated December, 1914.

TYPE F (See Fig. 4).—*Ballast.*—Seven inches of 1 to 3 inch crushed rock supporting 7½ inches of gravel concrete 1–4–8 mixture.

Ties.—Seven by eight inches by eight feet, oak, on 2-foot centers.

Rails.—Seven-inch, 90-pound girder, 4-inch base.

Spikes.—Six-inch, driven, four per tie.

Surface.—Same as for Type A.

TYPE G.—*Ballast.*—One to three inches, crushed stone, from 5 inches below ties to head of rails, 9 feet wide.

Ties.—Seven by eight inches by eight feet on 2-foot centers.

Rails.—Four-inch T.

Spikes.—Six-inch, driven, four per tie.

Surface.—No surfacing.

TYPE H.—*Ballast.*—Cinders from 5 inches below ties to base of rails.

Ties.—Seven by eight inches by eight feet, oak, on 2-foot centers.

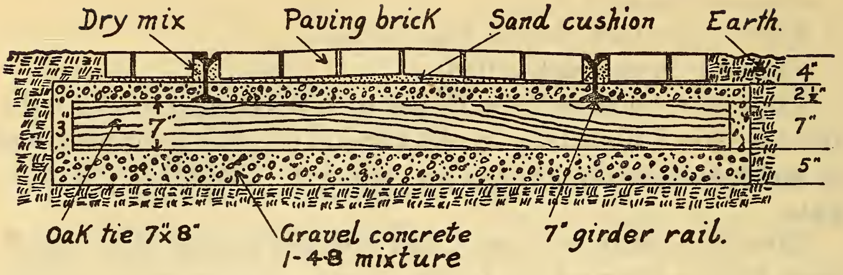
Rails.—Four-inch T.

Spikes.—Six-inch, driven, four per tie.

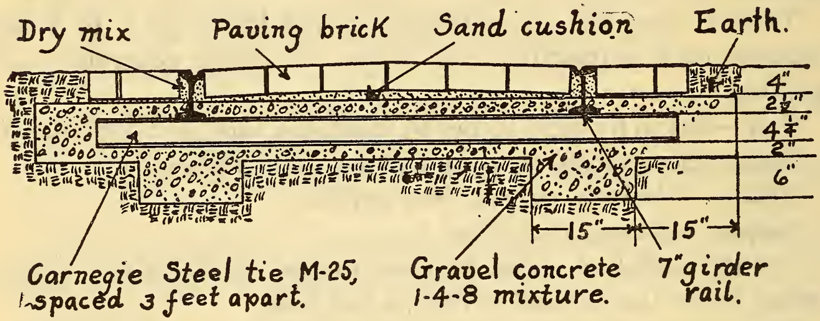
Surface.—Open construction.

In selecting these several types of roadbeds an attempt was made to include those most commonly used in practice as well as to introduce certain modifications in the way of insulating materials which it was thought might prove of practical value in reducing stray currents. Ties treated with several different kinds of preservatives were also used in order to determine the effect of such treatments on the resistance of the wood and the leaching effect of the weather on the different preservatives.

Type A, illustrated in Fig. 4, is of solid-concrete construction with brick pavement and was built to correspond with Type D, as recommended in 1914 by the way committee of the American



TYPE - A.



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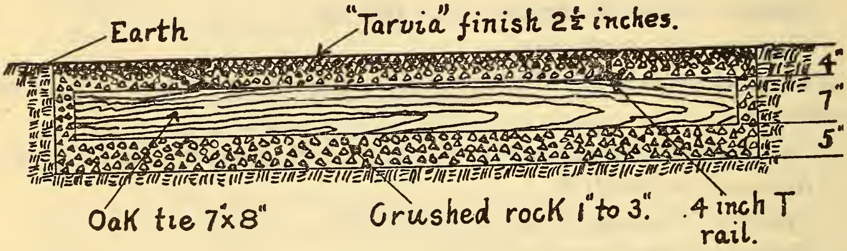
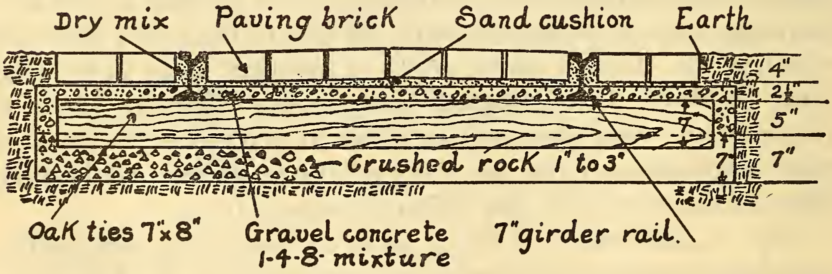


TYPE-C



TYPE-F.

FIG. 4.—*Types of experimental roadbeds*

Electric Railway Engineering Association. Types AT and AA are of the same construction as Type A but with insulating layers laid under the foundations as previously described.

Type B, shown in Fig. 4, is of concrete-beam construction with steel ties and corresponds closely with Type 3 described by the 1914 committee. Type BT is the same as Type B, but insulated as Type AT.

Type C, with crushed-rock ballast and Tarvia finish, is practically a duplication of the Chevy Chase line, which has already been described.

Type F, shown in Fig. 4, has crushed stone under the ties instead of a full-concrete ballast. Otherwise it is the same as Type A. This section corresponds to Type B of the 1914 recommendations and is the most popular type of construction for city streets as shown by that committee, and also by the report of an investigation conducted by the United Railways & Electric Co., of Baltimore, and described in the 1915 report of the way committee of the American Electric Railway Engineering Association. The 1915 committee also recommended this type of construction for a standard design. The resilience offered to the track by this type of ballast as compared to the rigid and unyielding features of the full-concrete type is largely responsible for the favor which it has found with the street railway engineers.

3. METHOD OF MAKING RESISTANCE MEASUREMENTS ON EXPERIMENTAL ROADBEDS

Each type of experimental track was constructed with a continuous 12-foot section of roadbed and with two 6-foot sections of rails, as shown in Fig. 3. The object of laying the rails in two sections was to enable independent resistance measurements to be made on the two longitudinal halves of the roadbed. This really permitted of four separate measurements on each track through the four 6-foot lengths of rails, by which variations and irregularities which might occur in any one type could be detected. Each piece of rail in the system was wired to a common terminal board where complete switching facilities were provided, whereby the resistance to a remote ground of any piece of rail or any full or half section of track could be accurately and quickly determined. The manner of making the measurements is briefly as follows: The positive terminal of a 10 or 12 volt battery of dry cells was connected to a mercury bus which in turn could be connected to any or all rail sections in parallel. The negative terminal of the battery was connected to a service pipe and thereby to the entire water-piping system of the city of Washington. The resistance of the circuit thus established may be said to include the leakage resistance between the tracks and the water-piping system and the resistance of the service pipe and other connections between the negative terminal of the battery and the piping system as a whole. This latter was measured by several different methods and at different times, and was invariably found to be about 1 ohm, a figure so small in comparison with the leakage resistance of the roadbeds that no correction was made for it in computing the latter. A voltmeter was connected across the terminals of the battery, and a milliammeter was so arranged that it could be connected in series with a part or all of any track section while the remainder of the sections in either of the two divisions were also being supplied with current from the positive bus. The object of supplying current to all sections of track while measurements were being made on only one section was to prevent end leakage from the section under test. Without this precaution it was found that fictitious results would be obtained resulting from the longitudinal leakage along the tracks across the short gaps between adjacent rails. Repeated measurements of the leakage from the four individual rails of the various sections revealed a remarkable degree of uniformity in each type, and only the unit resistivity of each type has therefore been recorded.

Observations were made of the polarizing effect resulting from the use of direct current and this was found to increase the apparent resistance of the roadbeds about 5 per cent after a period of 1 minute and to remain nearly constant during the 10 or 15 minutes required for a complete series of measurements. This effect was found to increase to about 10 per cent in an hour and a half. The apparent resistance has been recorded in each case and no attempt made to correct for polarization. The small current density employed is apparently responsible for the very small polarization effect observed, as intensified laboratory tests of a similar character on iron specimens in jars exhibit a very much more marked polarization.

4. RESULTS OF RESISTANCE MEASUREMENTS ON EXPERIMENTAL ROADBEDS

(*a*) CONCRETE BALLAST.—Resistance measurements were first made on the experimental roadbeds on April 5, 1915, shortly after their completion, and were repeated at irregular intervals for a period of about three years. A summary of the results of these measurements, together with a brief description of the condition of the roadbeds with respect to moisture and temperature, is given in Table 3. The same results are shown graphically in Figs. 5, 6, and 7, and show clearly the variations due to weather conditions as well as those due to the ageing of the tracks and roadbeds. In Fig. 5 are given the results of measurements on all types of roadbeds having full-concrete ballast. It is seen that the insulating materials used in Types AT, AA, and BT had a pronounced effect in increasing the resistance during the first few months, but that after a period of three years the difference in resistance between the insulated and uninsulated types was so small as not to justify the use of such materials as a mitigative measure. Other investigations of the Bureau of Standards also tend to show that practically all kinds of paints, coatings, and insulating compounds of this character become more or less conducting where continually subjected to moisture, and in the course of time partially or wholly lose their value as insulating mediums.

The resistances of the concrete roadbeds are seen to be very low in comparison with other types and to vary only moderately with the moisture content of the soil. Frozen ground, however, has a very marked effect on all types, as shown by the tests of January 13 and February 14, 1917. On the former date the ground was frozen to a depth of 4 or 5 inches and on the latter date, after an extended period of cold weather, the frost had penetrated to a much greater depth, probably 12 inches or more. Under this condition the resistances of the concrete roadbeds had risen to approximately double their normal values. The ageing of these roadbeds seem to have increased their resistances slightly, although this is not definitely established, owing to the limited number of measurements made during the last year.

There is practically no difference in resistance between the steel and wood tie construction and this would seem to indicate that most of the resistance in the leakage circuit is to be found between the concrete roadbed and the ground rather than between the rails and the surrounding concrete. It follows, therefore, that in city streets where this type of construction is employed, the greater extent of the concrete-pavement base might offer even less resistance to leakage currents than these experimental roadbeds.

TABLE 3.—Resistance to Earth of Experimental Roadbeds

[Resistance in Ohms Calculated for 1000 Feet of Single Track]

Date of test	Condition of roadbed	Type of construction													
		A	B	AA	AT	BT	D	DT	F	H	C	E	EC	EZ	G
April 5, 1915	Roadbed wet; 0.44 inch of snow on April 3	0.343	0.33	0.48	0.42	0.50	0.97	1.44	0.81	4.50	5.86	4.17	....	2.88	....
April 12, 1915	Surface moist; roadbed wet; rain on previous day	.27	.32	.61	.39	.41	.87	1.38	.83	3.29	4.66	2.72	3.94	.72	9.67
April 22, 1915	Surface dry; roadbed drier than on previous tests	.29	.29	.61	.42	.37	1.44	1.87	.93	4.35	4.67	3.58	6.65	1.04	52.2
June 7, 1915	Surface dry; roadbed wet; heavy rain on June 2	.27	.27	.48	.39	.33	.86	1.43	.78	1.92	4.15	3.11	3.41	.92	10.9
June 29, 1915	Surface dry; roadbed fairly dry; no rain for several days	.31	.30	.55	.45	.34	1.21	1.73	.98	2.54	4.05	3.60	4.48	1.67	29.6
July 21, 1915	Roadbed quite wet; rain on previous day	.28	.29	.45	.38	.32	.55	1.03	.72	1.00	2.78	2.89	1.93	.72	6.1
Aug. 19, 1915	Surface dry; roadbed moist, not wet	.31	.28	.64	.38	.29	.78	1.09	.88	1.20	3.40	3.14	3.14	1.26	8.8
Sept. 24, 1915	Surface dry; roadbed moist, not wet	.33	.34	.69	.41	.30	.86	1.20	.92	1.03	3.34	4.08	3.84	1.58	9.4
Oct. 29, 1915	Surface dry; roadbed moist, not wet	.33	.31	.69	.42	.33	.84	1.17	.87	1.16	3.25	3.20	3.25	1.42	6.10
Dec. 4, 1915	Cold; roadbed moist; no rain for several days.	.40	.34	.95	.57	.40	1.32	2.26	1.02	1.87	5.15	5.67	6.00	2.17	11.7
Jan. 21, 1916	Surface wet; ground thawing out from 6-inch freeze	.40	.38	.94	.59	.41	1.08	1.84	1.35	2.59	4.80	3.82	3.98	1.55	8.21
Mar. 20, 1916	Cold; surface dry; ground moist	.42	.37	.91	.59	.41	1.25	2.26	1.23	3.01	5.18	4.21	5.17	2.16	10.8
April 19, 1916	Warm; surface dry; ground moist	.40	.35	.54	.53	.39	1.22	1.87	1.16	2.32	4.56	3.86	5.10	2.35	10.5
Aug. 24, 1916	Surface dry; ground moist; rain on previous day	.35	.35	.44	.46	.34	.92	1.39	1.11	1.63	3.42	2.98	3.02	2.29	6.6
Jan. 13, 1917	Ground frozen 4 or 5 inches deep	.66	.46	.75	.92	.51	1.33	2.62	1.50	5.22	8.16	8.21	6.50	3.60	17.3
Feb. 14, 1917	Ground frozen deep; surface beginning to thaw	.89	.67	1.1	1.24	.84	2.20	3.58	3.36	7.50	8.37	6.40	7.75	3.73	13.3
Mar. 15, 1917	Surface dry; ground very wet	.45	.47	.60	.61	.43	.95	1.58	1.21	2.19	5.24	2.89	3.72	1.62	4.9
Oct. 3, 1917	Surface and ground very dry; driest condition.	.44	.50	.51	.61	.41	1.33	1.64	1.38	2.25	4.38	6.35	4.68	5.58	9.8
Mar. 20, 1918	Surface dry; ground wet	.45	.41	.60	.64	.45	.83	1.25	1.16	1.98	4.68	3.89	3.24	2.04	6.4

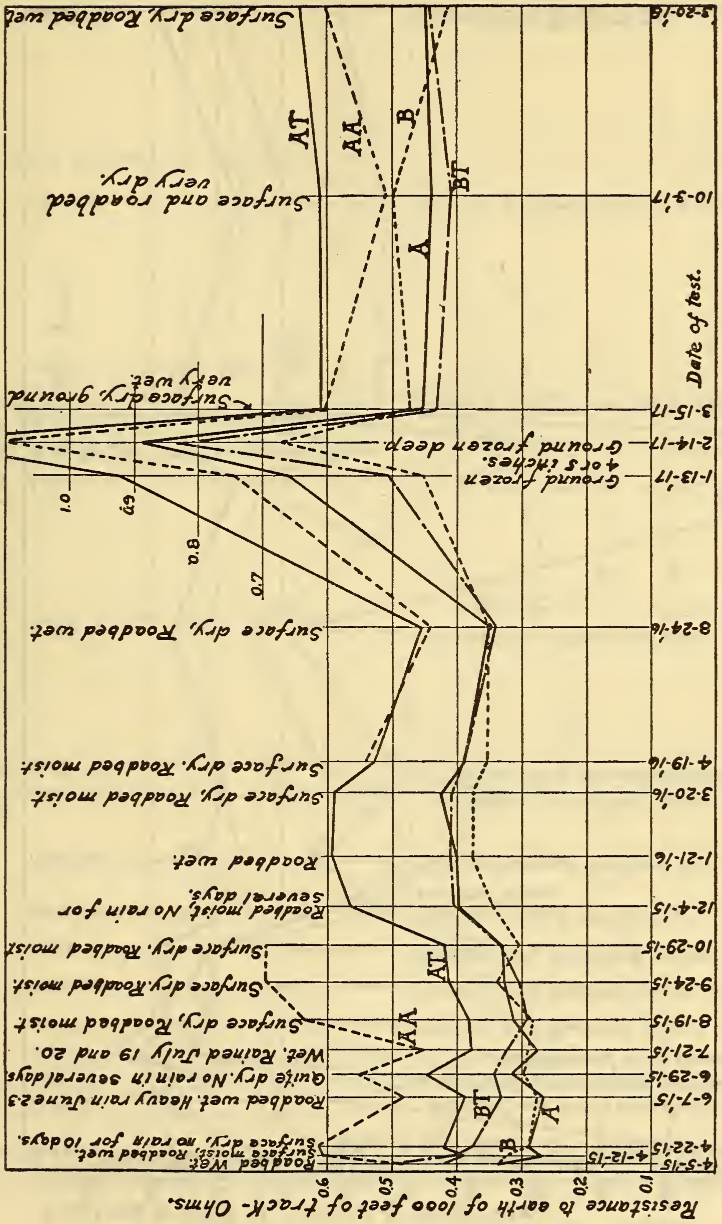


FIG. 5.—Resistance of experimental roadbeds

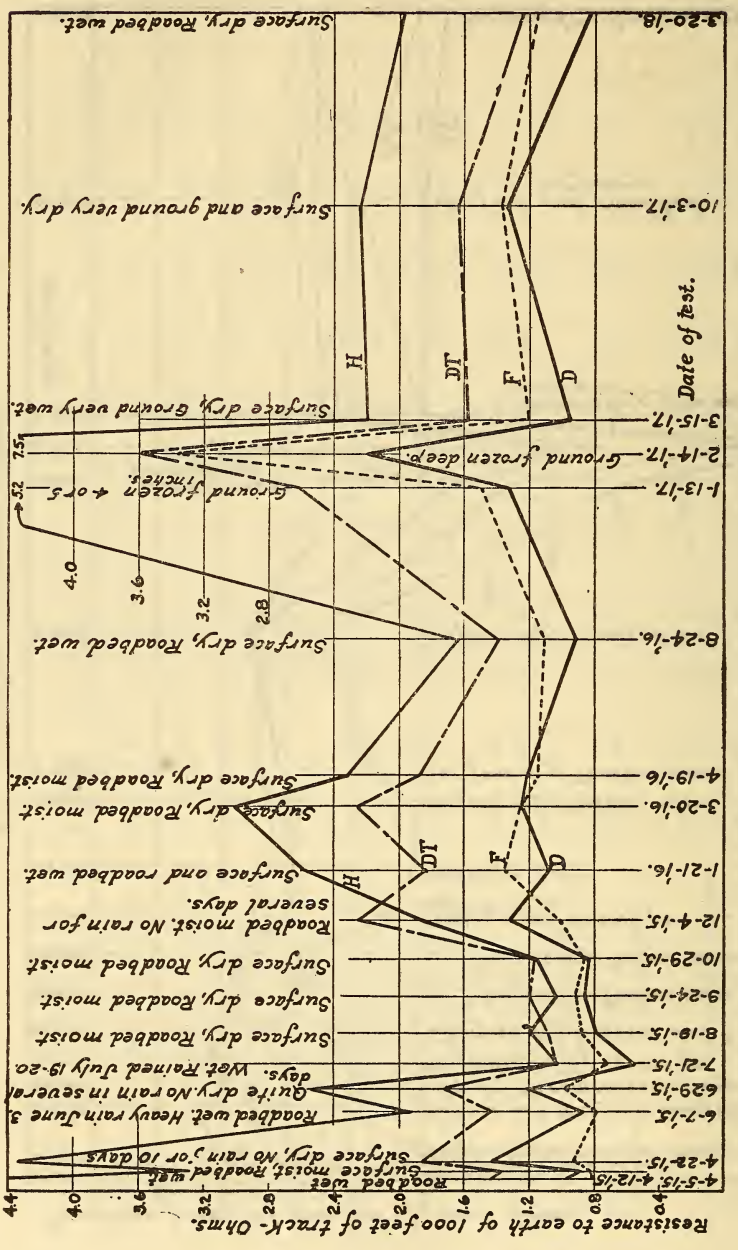


FIG. 6.—*Resistance of experimental roadbeds*

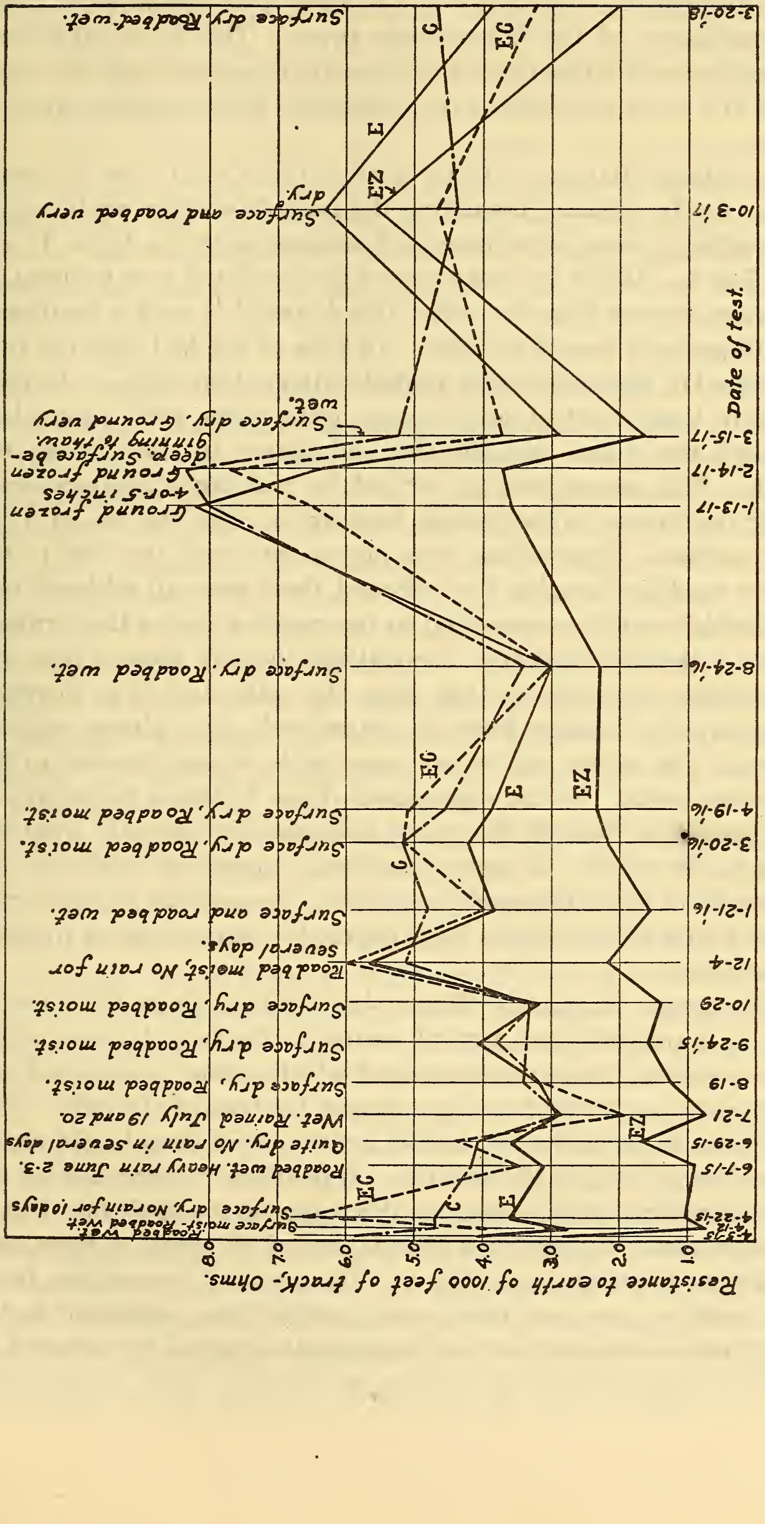


FIG. 7.—Resistance of experimental roadbeds

(*b*) CRUSHED-ROCK FOUNDATION.—Type F, with a crushed-rock foundation, is seen in Fig. 6 to have from two to three times the resistance of the full-concrete types. This is an additional advantage which this type of construction possesses over the more rigid and more expensive type employing a full-concrete foundation.

(*c*) EARTH BALLAST, WITH RAILS INSULATED AND UNINSULATED.—The effect of insulating the rails themselves with a coal-tar coating is seen in the results of measurements on Types D and DT, Fig. 6. While the resistance of the insulated type is about 50 per cent greater than the other, it is doubtful if such a treatment would prove of practical value. In view of the fact that the rails of Type DT were effectively coated with coal-tar pitch, it is quite evident that most of the leakage from these rails took place through the spikes into the ties and thence to the surrounding earth. This assumption is verified by resistance measurements made on dummy spikes which were driven into the ties of Type DT roadbed. Four spikes were driven into each tie close to the spikes used for securing the rails and these were all soldered to a wire which could be connected to the positive bus at the terminal board. It was found that the leakage through these spikes was practically the same as that from the rails, and it is therefore apparent that leakage from the latter took place almost entirely through the spikes and to no appreciable extent directly to the adjacent earth. In the uninsulated Type D about two-thirds of the leakage is through the spikes and one-third directly from the rails to the earth. If some practicable means of insulating the spikes from the rails could be devised, the problem of stray currents would be solved to a large degree for many kinds of roadbed construction.

(*d*) CINDER BALLAST.—The cinder roadbed, Type H, shown in Fig. 6, is probably not typical, owing to the fact that soon after its completion heavy rains occurred which washed much sand and earth into the basllast and up around the base of the rails. This condition is probably responsible for the rapid drop in the resistance during the first few months. It is difficult to account for the wide variations which occur in this type of roadbed, but this is characteristic, though to a less degree, of all types of open construction, as evidenced in Fig. 7. Ties exposed to sunshine, frost, and rain vary in resistance greatly, while those embedded in the earth or in concrete are not appreciably affected by seasonal or daily changes. Owing to the poor drainage provided for Type H roadbed and the presence of much fine sand and earth in the ballast, the results obtained on the Cabin John line and recorded in Table 1 should be accepted as typical of this kind of construction rather than those for the experimental track.

(*e*) OPEN CONSTRUCTION WITH TREATED AND UNTREATED TIES.—In Fig. 7 are shown the results of measurements on Types E, EC, and EZ roadbeds, all of the same open-type construction but with differently treated ties. These roadbeds are comparatively well drained and the earth has been kept out of contact with the base of the rails. There is seen to be but little difference between the untreated ties in Type E and those of Type EC which were treated with about 10 pounds of creosote per cubic foot. Both have an average resistance of about 4 ohms for 1000 feet of track, which is much higher than that of most of the roadbeds employed in city streets. These resistances are somewhat lower than those found for the Cabin John and the Washington, Baltimore & Annapolis tracks, owing to the use of earth ballast instead of the more highly resistive materials.

The effect of the zinc-chloride treatment is strikingly shown in the record of tests on Type EZ roadbed. During the first year the resistance was only about one-third that of the other types, but has gradually increased until after three years the effect of the treatment has almost disappeared. This is undoubtedly due to the leaching out of the treating material.

Dummy spikes were driven in the ties of these roadbeds, as in Type DT, and by measurements on them it was found that practically all leakage from the rails takes place through the spikes and little if any directly from the base of the rails into the ties.

(*f*) CRUSHED-ROCK BALLAST WITH AND WITHOUT PAVEMENT.—Type C roadbed, shown in Fig. 7, offers the highest resistance to leakage currents of any kind of roadbed for city streets that we have investigated. The clean stone and nonporous surface employed in this construction is responsible for the high resistance, but it is doubtful if such a condition could be long maintained in city streets under traffic conditions. The incessant pounding of cars on the tracks loosens the bond between the pavement and the rails and permits the entrance of moisture, which not only washes fine materials into the ballast, but saturates the roadbed. The average resistance of this roadbed, which is about 5 ohms for 1000 feet, is more than twice that of the Chevy Case line of similar construction. The cause for this is to be found largely in the foregoing explanation. It should be noted that the figures for the Chevy Chase line are for double track and the corresponding resistance for single track would be nearly twice as great, or, roughly, 2 ohms for 1000 feet.

Type G roadbed made with crushed-rock ballast, but no paving, has an unusually high resistance, as shown in Table 3. The resistance has diminished considerably with time due to the earth and sand which has been washed into the roadbed. The figures for this piece of roadbed show what might be accomplished by the use of a well-drained and clean, crushed-rock or gravel ballast.

(*g*) RELATIVE RESISTANCES OF DOUBLE AND SINGLE ROADBEDS.—No direct measurements have been made on city tracks to determine the relative resistance of single and double track roadbeds. It may safely be assumed, however, that where high-resistance roadbeds are involved, the leakage from a double track will be nearly twice that from a single track. With concrete or earth ballast and other types of low-resistance roadbeds where a large part of the total resistance is encountered at a relatively great distance from the rails, the resistance of a single-track roadbed approaches that of double-track construction. Tests made on the two divisions of the experimental tracks show that the leakage from both divisions in parallel is about 40 per cent greater than that from either division alone. All types of constructions were of course involved in this test, but as about 80 per cent of the total leakage took place from the concrete roadbeds, it may be assumed that these types dominated the results. The two divisions are 18 feet apart, center to center, which is much more than the usual spacing, and this factor tends to increase the leakage from the two divisions over what it would be with a more normal spacing. We may safely say, therefore, that the leakage from double-track construction of very low resistance types is not anything like double that from single track, and may be in some cases not more than 25 per cent greater. The leakage for other types would range from 25 per cent to 100 per cent more for double than for single track, depending upon the character of the roadbed.

V. RESISTANCE MEASUREMENTS ON TREATED AND UNTREATED WOOD TIES

In order to determine the effect of moisture and different preservative treatments on the resistance of wood ties, the following six specimens were selected from among the ties obtained for the construction of the experimental roadbeds: No. 1, white oak, untreated; No. 2, red oak, untreated; No. 3, chestnut, untreated;

No. 4, red oak, treated by the Baltimore & Ohio Railroad Co., in October, 1914, with 10 pounds of coal-tar creosote per cubic foot, by the vacuum-pressure treatment; No. 5, red oak, treated by the Baltimore & Ohio Railroad Co., in December, 1914, with one-half pound of zinc chloride and 2 pounds of coal-tar creosote per cubic foot, by the Card process; and No. 6, red oak, treated by the Chicago, Burlington & Quincy Railroad Co., with about one-half pound of zinc chloride per cubic foot.

These ties were saturated by placing them in shallow vessels filled with water to a depth of about 2 inches. They were turned over from time to time and kept covered with burlap which was wet with a hose daily. After two weeks of this treatment they were placed indoors and their weights and resistances measured at intervals covering a period of three years.

Resistance measurements were made by the ammeter-voltmeter method in the following manner: Two iron railroad spikes were driven near each end of the tie to act as current terminals, these being 5½ feet apart. Two spikes for potential terminals were driven 9 inches from the current terminals, or 4 feet apart. Current was supplied from a 260-volt storage battery and a milliammeter was employed to measure the longitudinal current flow through the tie. The fall of potential between the potential terminals was measured with a Paul Unipivot galvanometer connected in series with a megohm of resistance. With this arrangement the error due to the contact resistance of the spikes used for potential terminals was negligible, except for the last measurement which was made after the resistances had reached extremely high values and only approximate results could therefore be obtained. The results of these measurements are given in Table 4 and also shown graphically in Fig. 8. The per cent of moisture as calculated in each case is based on the assumption that the ties were dry at the time of the last measurement. The form of the curves indicates that this assumption is practically correct, although it is of course impossible to extract the last bit of moisture from wood by air drying, particularly from those specimens which were treated with creosote.

From this series of tests it appears that moisture in excess of 20 or 25 per cent has little effect in reducing the electrical resistance of wood, while with less than about 10 per cent of moisture the resistance increases rapidly. Chestnut wood dries out in the air more readily than oak and therefore has a higher resistance for a given time of air drying. For the same moisture content, however, its electrical properties are about the same as oak.

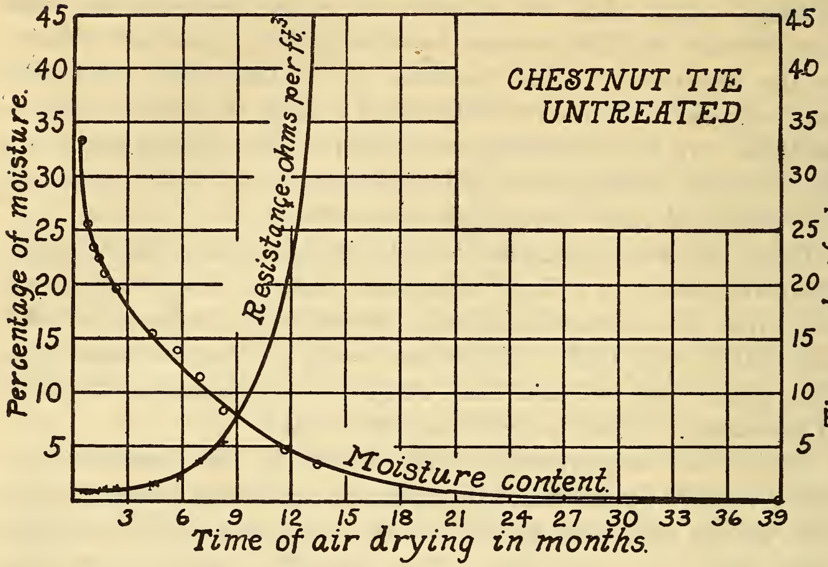


FIG. 8 (*a*)

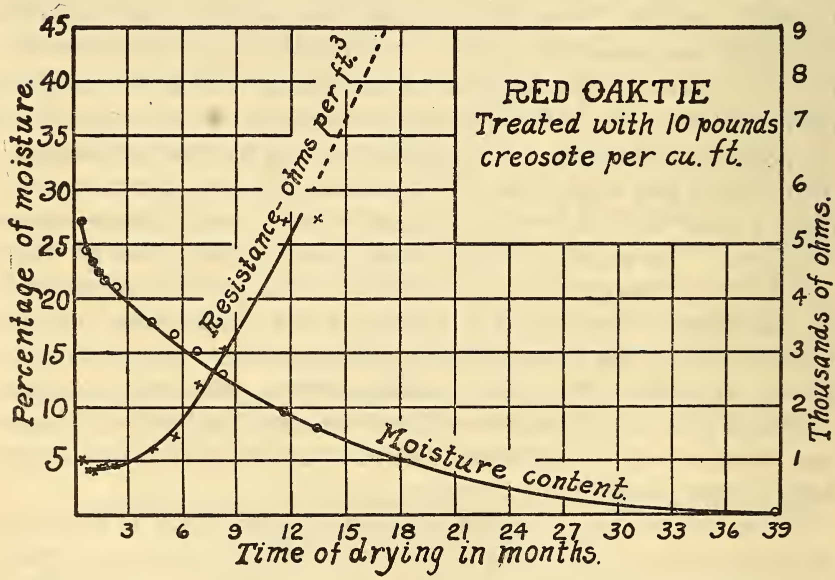


FIG. 8 (*b*)

Variation of moisture content and resistivity of wood ties with time of air drying

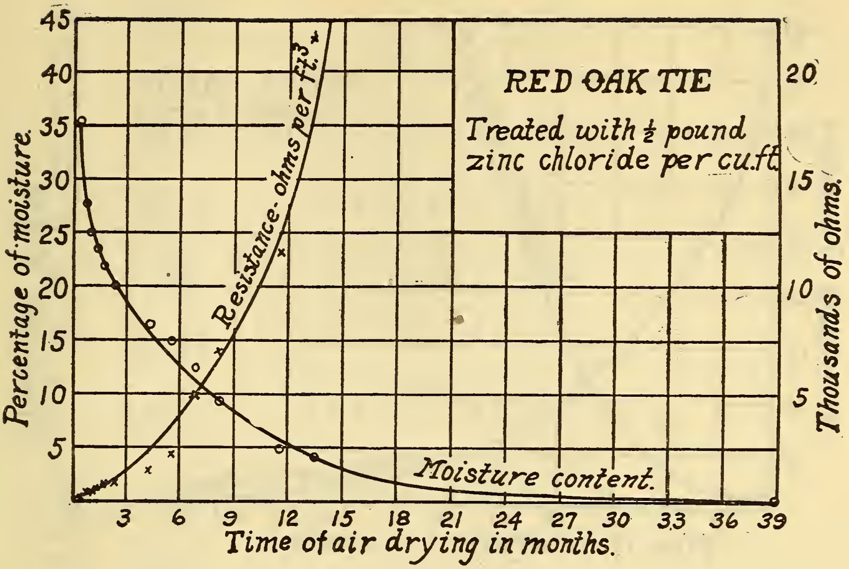


Fig. 8 (*c*)

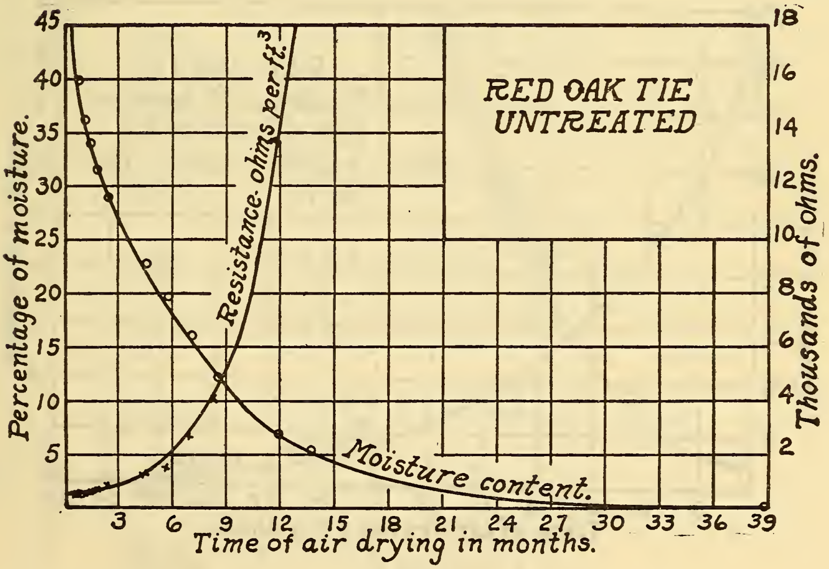


Fig. 8 (*d*)

Variation of moisture content and resistivity of wood ties with time of air drying

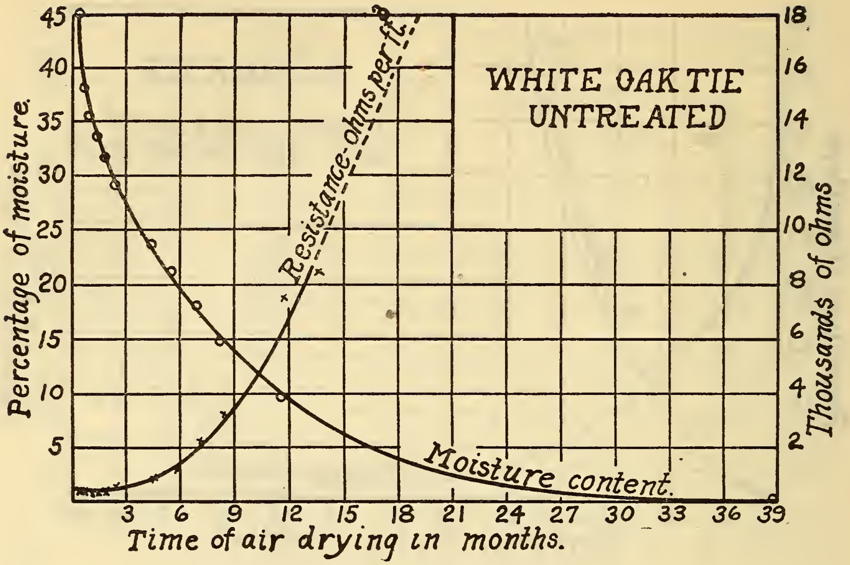


FIG. 8 (e)

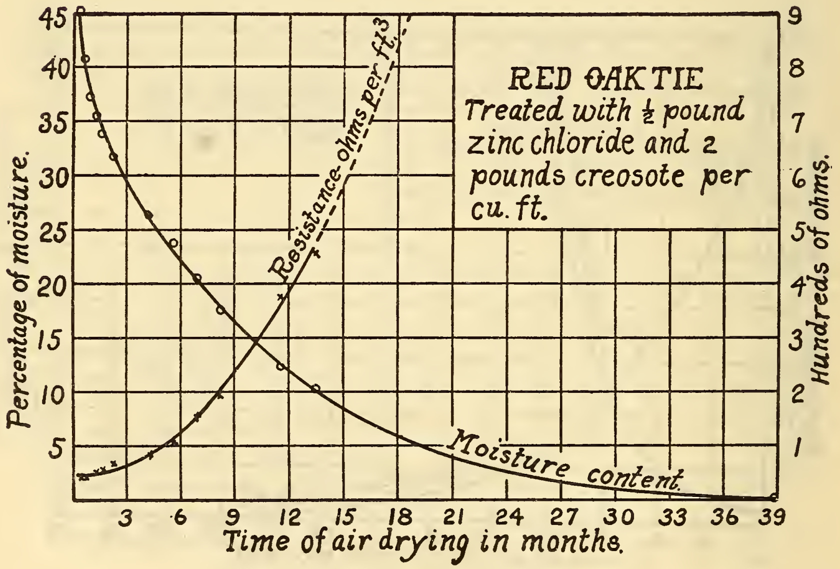


FIG. 8 (f)

Variation of moisture content and resistivity of wood ties with time of air drying

TABLE 4.—Variation of Moisture Content and Resistivity of Wood Ties With Time of Air Drying

Date of test	No. 1. White oak, untreated			No. 2. Red oak, untreated			No. 3. Chestnut, untreated			No. 4. Red oak, treated with 10 pounds creosote per cubic foot			No. 5. Red oak, treated with creosote and zinc chloride			No. 6. Red oak, treated with zinc chloride only		
	Weight, pounds per cubic foot	Per cent moisture	Resistance, ohms per foot cube	Weight, pounds per cubic foot	Per cent moisture	Resistance, ohms per foot cube	Weight, pounds per cubic foot	Per cent moisture	Resistance, ohms per foot cube	Weight, pounds per cubic foot	Per cent moisture	Resistance, ohms per foot cube	Weight, pounds per cubic foot	Per cent moisture	Resistance, ohms per foot cube	Weight, pounds per cubic foot	Per cent moisture	Resistance, ohms per foot cube
Apr. 12, 1915	68. 2	45. 7	513	61. 1	48. 3	536	52. 0	33. 0	834	58. 8	27. 2	1020	67. 3	45. 2	46. 9	57. 3	35. 5	177
Apr. 21, 1915	64. 7	38. 3	457	57. 6	39. 8	530	49. 1	25. 5	822	57. 5	24. 5	871	65. 2	40. 7	46. 7	54. 0	27. 6	387
May 1, 1915	63. 5	35. 6	493	56. 1	36. 1	568	48. 3	23. 5	875	57. 1	23. 5	822	63. 5	37. 1	....	52. 9	25. 0	461
May 10, 1915	62. 6	33. 7	525	55. 2	34. 0	632	47. 9	22. 5	917	56. 7	22. 5	905	62. 8	35. 5	56. 3	52. 3	23. 7	565
May 21, 1915	61. 6	31. 6	618	54. 2	31. 5	770	47. 3	21. 0	1054	56. 3	21. 7	1000	62. 0	33. 8	60. 0	51. 6	22. 0	698
June 9, 1915	60. 5	29. 3	757	53 2	29. 1	890	46. 8	19. 6	1112	56. 0	21. 2	945	61. 0	31. 7	69. 7	50. 8	20. 0	765
Aug. 9, 1915	57. 9	23. 7	1003	50. 5	22. 6	1257	45. 2	15. 5	1627	54. 5	18. 0	1225	58. 5	26. 3	86. 4	49. 2	16. 4	1450
Sept. 17, 1915	56. 8	21. 3	1327	49. 3	19. 6	1504	44. 6	14. 0	2140	54. 0	16. 9	1473	57. 3	23. 7	103. 0	48. 5	14. 9	2190
Oct. 29, 1915	55. 3	18. 2	2455	47. 8	16. 0	2680	43. 6	11. 5	3590	53. 2	15. 1	2445	55. 8	20. 5	159. 0	47. 5	12. 3	4990
Dec. 4, 1915	53. 7	14. 8	3460	46. 2	12. 1	4130	42. 4	8. 4	5200	52. 2	13. 0	3060	54. 4	17. 5	196. 0	46. 2	9. 2	7100
Mar. 16, 1916	51. 3	9. 6	7670	44. 0	6. 8	13 680	41. 0	4. 8	27 400	50. 7	9. 7	5440	52. 0	12. 3	377. 0	44. 4	4. 9	11 650
May 13, 1916	50. 4	7. 7	8600	43. 5	5. 5	19 820	40. 5	3. 5	47 000	50. 0	8. 2	5480	51. 1	10. 3	458. 0	44. 0	4. 0	21 600
June 27, 1918	46. 8	. 0	(*a*)	41. 2	. 0	(*a*)	39. 1	0	(*a*)	46. 2	. 0	(*b*)	46. 3	. 0	9380. 0	42. 3	. 0	(*a*)

a Very high.

b More than 100,000.

Creosoting tends to retain what moisture is within the wood and to retard the drying-out process, but otherwise has little effect upon its electrical resistance. Tie No. 5, which was treated with both creosote and zinc chloride, exhibited a very low resistance, much lower than No. 6, which contained zinc chloride only. The history of No. 6 is not well known, and it is altogether probable that much of the zinc chloride had leached out in the weather before the test was started. In the Card process, the effect of the creosote is to hold the zinc chloride as well as the moisture, and it is no doubt this condition which is responsible for the very low resistance of No. 5. These ties are from the same groups as those used in Types EC and EZ of the experimental roadbeds.

Ties embedded in the earth or in paved city streets would probably retain moisture in excess of 20 per cent throughout the year and therefore would not change their resistance materially with seasonable changes. On the other hand, in open construction the moisture content, and therefore the resistance, would vary through wide limits.

VI. RESISTANCE OF STEAM RAILWAY ROADBEDS[3]

1. ARRANGEMENTS FOR JOINT INVESTIGATION

In September, 1915, an agreement was entered into between the Forest Products Laboratory at Madison, Wis., and the Chicago, Milwaukee & St. Paul Railway Co., whereby ties treated by the Forest Products Laboratory with different kinds of preservatives were to be installed in the railway company's tracks in or near Madison and records kept of the performance of the different treatments.

The Bureau of Standards learned that such tests were contemplated and suggested to the Forest Products Laboratory that arrangements be made to include in the tests electrical resistance measurements of the different roadbeds. With the concurrence of the Forest Products Laboratory and the railway company in this matter provision was made for such measurements, and accordingly the railway company electrically isolated 7 test sections from each other by bonding all rail joints in each section and installing insulated joints between the several sections.

2. DESCRIPTION OF TEST TRACKS

The test tracks were installed on the Chicago, Milwaukee & St. Paul Railway near the Fair Grounds at Madison, in November, 1916. The track is on sandy-gravel ballast with 75-pound rail laid with opposite joints and 6½ by 8½ inch Illinois Steel Co. No. 464 tie-plates, single spiked with ordinary $\frac{9}{16}$-inch cut spikes. Bonzano rail joints without tie-plates were used except at the ends of each section, where insulated joints were necessary. The insulated joints were simply angle bars with insulating material between them and the rails and between the ends of the rails. Each section was 165 feet in length and contained 100 ties. The rails for the most part were out of contact with the ballast. The arrangement and a brief description of the several sections are given in Fig. 9, and a more detailed description of the different treatments follows:

---

[3] Measurements made in collaboration with U. S. Forest Products Laboratory of Madison, Wis.

Section 1.—Red-oak ties, treated at a commercial plant with 0.55 pound of zinc chloride per cubic foot. A 4 per cent solution of the preservative at a temperature of 150° F was used under a pressure not stated for five hours. No initial or final vacuum was drawn. The ties were seasoned one year before and one year after the treatment.

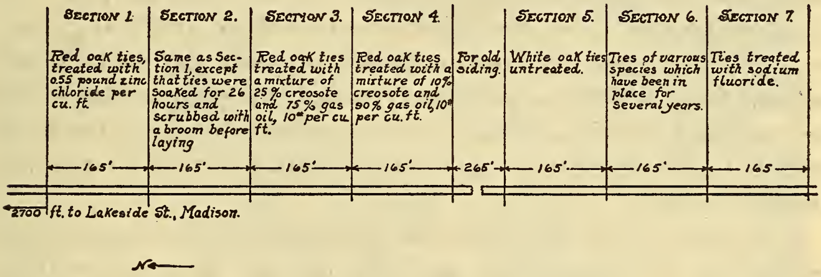

Section 1.
Red oak ties, treated with 0.55 pound zinc chloride per cu. ft.
Section 2.
Same as Section 1, except that ties were soaked for 26 hours and scrubbed with a broom before laying
Section 3.
Red oak ties treated with a mixture of 25% creosote and 75% gas oil, 10# per cu. ft.
Section 4.
Red oak ties treated with a mirture of 10% creosote and 90% gas oil, 10# per cu. ft.
For old siding.
Section 5.
White oak ties untreated.
Section 6.
Ties of various species which have been in place for several years.
Section 7.
Ties treated with sodium fluoride.
165'
165'
165'
165'
265'
165'
165'
165
2700 ft. to Lakeside St., Madison.
N

Fig. 9.—*Arrangement of test tracks on C., M. & St. P. Ry. at Madison, Wis.*

Section 2.—The same as section 1, except that the ties had been soaked in the lake for 26 hours and scrubbed with a broom before laying.

Section 3.—Red-oak ties treated by the Forest Products Laboratory with a mixture of 25 per cent creosote and 75 per cent gas oil, with an average absorption of about 10 pounds per cubic foot. The ties were seasoned for 18 months before and 6 months after treatment. The oil was a parafine-base crude oil from which the gasoline and other volatile oils had been removed by distillation. This oil was obtained from the stock of the local gas company, which uses it in the manufacture of water gas.

Section 4.—The same as section 3, except that a mixture of 10 per cent creosote and 90 per cent of gas oil was used.

Section 5.—White-oak ties, untreated.

Section 6.—Ties of various species which had been in place for several years.

Section 7.—Red-oak ties treated by the Forest Products Laboratory with 0.515 pound of sodium fluoride per cubic foot. A 3.35 per cent solution of the preservative and a temperature of about 150° F were used, with a maximum pressure of 150 pounds per square inch. The treatment consisted of a preliminary vacuum of 1 hour followed by a pressure period of approximately 3 to 6 hours, with a 15-minute final vacuum. The ties were seasoned about 1 year before and 2½ months after treatment.

3. METHODS OF MAKING RESISTANCE MEASUREMENTS

Neither the differential nor the isolation method as previously described were suitable for making resistance measurements on the steam-railroad test tracks. No water-piping system was available for an earth connection and the track network, not being bonded, could not well be employed for this purpose. It therefore became necessary to either establish an artificial ground or to make a series of measurements between the various test sections from which the resistance to earth of each section could be computed. This latter method was selected as being the more desirable and measurements were accordingly made in the following manner:

A battery of four dry cells was connected between two remote sections of the test tracks and the current flow and voltage observed. This was repeated for various pairs of sections according to the following schedule: Between sections 1 and 5, 2 and 5, 3 and 5, 4 and 5, 4 and 6, 1 and 4, and 4 and 7.

From the results of this series of measurements it was possible to set up a number of equations, the simultaneous solution of which gave the resistance of each section to earth. Fig. 10 shows the apparatus used in making these tests. The first set of measurements was made by a representative of the Bureau of Standards, assisted by members of the Forest Products Laboratory staff. All subsequent tests were made by the Forest Products Laboratory and the results sent to the Bureau of Standards.

4. RESULTS OF MEASUREMENTS

After the first two series of measurements were made it was decided to record the resistance between the rails of each section, as such measurements would act as a check on the others and would be of particular value to signal engineers, who are more concerned with the leakage between rails than with the leakage to earth. The results of measurements taken over a period of about

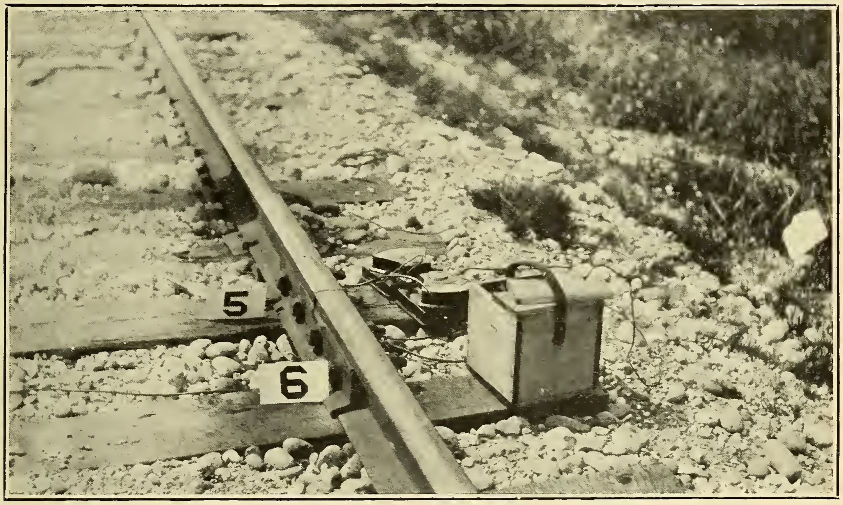


Fig. 10.—*Dry-cell battery and instruments used in making resistance measurements of steam-railway roadbeds*

16 months are given in Table 5. The resistances are calculated for a single track having 500 ties, which corresponds to 1000 feet of track with 2-foot spacing of the ties. As the ties in these test sections are spaced about 20 inches, center to center, the figures in the table are for 825 feet of track. It should be noted that on open construction such as that employed in these tracks the leakage currents would be proportional to the number of ties or spikes, while in paved streets this would not be strictly true.

Although the measurements indicate considerable variation in the resistances of the several roadbeds, due to changing weather conditions and maintenance work on the tracks, the results are in substantial agreement with those obtained by laboratory and field tests at the Bureau of Standards. Sections 1 and 2, in which ties treated with zinc chloride were used, are seen to have a much lower resistance than the sections employing untreated ties or ties treated with oil and creosote. There is little difference between these two sections. The one in which the scrubbed ties were used shows a slightly higher resistance than the other, as would be expected. The leaching-out process is a slow one and requires more than a single washing. Only two measurements were made on section 7, employing ties treated with sodium fluoride, but they indicate that this treatment has about the same effect on the resistance as zinc chloride. The average resistance of these roadbeds is only a little greater than that found for Type EZ roadbed where ties treated with zinc chloride were also used. The higher values are probably due to the gravel ballast employed on the Madison roadbeds as against the earth ballast used at the Bureau of Standards.

In the records of sections 3 and 4 the effect of the gas-oil treatment is strikingly shown. The resistance of both sections are much higher than those with untreated ties, or than Section EC at the Bureau of Standards for which a straight creosote treatment was used. It is unfortunate that a more direct comparison between these two kinds of treatment was not possible. In section 3, 75 per cent, and in section 4, 90 per cent of the treating material was gas oil. The resistances of the two sections are about the same. It appears that the oil is more effective than straight creosote in excluding moisture from the ties, and therefore in rendering them better insulators. However, in view of the fact that the two lots of material were obtained from entirely different sources and placed in roadbeds under quite different conditions, it is impossible to make a reliable comparison. The oil treatment may offer some possibilities in the way of reducing leakage currents and may prove just as effective as creosote in preserving the wood against decay.

TABLE 5.—Resistance to Earth and Resistance Between Rails of Test Tracks on the Chicago, Milwaukee & St. Paul Railroad Near Madison, Wis.

Date of test	Condition of roadbed	Resistance in ohms, calculated for 500 ties or the equivalent of 1000 feet of single track with 2-foot spacing of ties													
		Sec. 1. Zinc chloride		Sec. 2. Zinc chloride, scrubbed		Sec. 3. 25 per cent creosote, 75 per cent gas oil		Sec. 4. 10 per cent creosote, 90 per cent gas oil		Sec. 5. White oak, untreated		Sec. 6. Old ties		Sec. 7. Sodium fluoride	
		To earth	Between rails	To earth	Between rails	To earth	Between rails	To earth	Between rails	To earth	Between rails	To earth	Between rails	To earth	Between rails
Mar. 6, 1917	Ballast frozen; surface thawed; ties wet........	5.0	....	5.4	....	15.2	....	15.9	....	5.9	....	11.4	....	....	....
Mar. 16, 1917	Track covered with snow and very wet........	2.3	....	2.4	....	11.8	....	10.6	....	6.7	....	5.7	....	....	....
Apr. 12, 1917	Ties dry; ballast damp and soft........	2.4	5.2	1.91	6.5	18.3	58.2	18.2	53.5	10.3	30.2	5.7	16.2	....	....
May 17, 1917	Ties quite dry; no rain for more than 1 month........	[a]1.04	[a]2.76	[a]1.20	[a]3.9	[a]12.4	[a]41.8	[a]10.1	[a]29.7	[a]8.4	[a]25.7	[a]6.5	[a]15.1	....	....
June 8, 1917	Ties dry on top; ballast quite wet........	1.52	2.32	1.92	3.3	5.3	19.0	5.3	18.9	3.7	11.5	2.9	7.1	....	....
Aug. 6, 1917	Ties and ballast dry; no rain for 2 months........	2.6	4.2	3.8	7.8	10.4	39.8	9.0	32.4	4.2	15.3	5.8	19.4	....	....
Sept. 14, 1917	Surface dry; heavy rain few days before........	1.52	3.1	1.82	3.8	4.7	17.7	4.6	17.1	3.6	11.7	2.7	8.0	....	....
Oct. 25, 1917	Surface of ties and ballast wet..	2.28	5.9	2.74	7.3	8.3	35.0	8.2	34.8	4.5	19.3	3.1	9.4	1.76	2.2
July 12, 1918	Surface dry; no rain for several days.	2.69	5.9	3.61	8.7	8.0	29.7	6.3	21.7	6.0	18.8	6.4	13.8	2.26	4.0
	Average........	2.37	4.2	2.76	5.9	10.5	34.5	9.8	29.7	5.9	19.0	5.6	12.7	2.01	3.1

[a] Between April 12 and May 17 the track was regaged and resurfaced and many of the spikes tapped with a spike maul.

The resistances of sections 5 and 6, in which new and old untreated ties were used, respectively, are about twice that found for the roadbeds with chemically treated ties and about one-half that found for tracks with oil-treated ties. They agree closely with the measurements on Type-E roadbed at the Bureau of Standards, as shown in Table 3, and with those on the Washington, Baltimore & Annapolis tracks, as shown in location (g), Table 1.

The resistance between the two rails of each track will be of particular interest to signal engineers. For the sections measured it is from two to three times as great as the corresponding resistances to earth.

VII. CONCLUSIONS

While an accurate interpretation of the foregoing results is not always possible, owing to many questionable elements such as weather and roadbed conditions and the properties of materials, the following general conclusions may be drawn:

1. Roadbeds constructed with solid-concrete ballast and vitrified brick, or other nonporous pavements, have a low leakage resistance to earth, which is affected only moderately by seasonal and weather changes. There is little difference between wood and steel ties in their effects on the resistance of roadbeds of this kind. Insulating layers of bituminous materials are not of practical value in reducing leakage currents from such roadbeds. The resistance of 1000 feet of single roadbed of this type is from 0.2 to 0.5 ohm under ordinary conditions, but may be double or treble these values when the ballast is frozen to a depth of 1 foot or more. For double roadbed of this type the resistance is approximately 70 per cent of that for single roadbed, or the leakage from double track would be about 40 to 50 per cent greater than from single track.

2. Roadbeds constructed with a foundation of clean, crushed stone under a concrete paving base have a much higher resistance than roadbeds with a solid-concrete ballast. In the case of the experimental roadbeds the ratio was found to be about 3 to 1.

3. Roadbeds with a full crushed-stone ballast and a Tarvia finish have a very high leakage resistance, which is of the order of 2 to 5 ohms for 1000 feet of single track. The leakage from a double roadbed of this type and other high resistance types is from 80 to 100 per cent greater than from single roadbeds.

4. The resistance of earth roadbeds in which the ties are embedded, and therefore kept in a moist condition, is much lower

than that of open-construction roadbeds, being from 1 to 1.5 ohms for 1000 feet of single track under normal conditions and considerably more when the ground is frozen.

5. The resistance of roadbeds of open construction is subject to wide variations, depending on the condition of the ties and ballast. In very dry weather with good ballast the resistance will be 10 to 15 ohms, and even more for 1000 feet of single track, but when wet will drop to from 3 to 5 ohms. Cinders, gravel, and particularly crushed stone, when used as ballast in open-track construction, produce very high resistance roadbeds. Earth has a tendency to keep the ties moist and therefore increases the leakage.

6. Open-construction track is often considered as being insulated from the earth, but this is not strictly true, even though the leakage may not be in harmful amounts when compared with other types of construction. Assuming a potential difference between a track and the earth of 5 volts and a leakage resistance of 10 ohms per 1000 feet of single roadbed, the total leakage per mile of track would be 2.64 amperes. This small leakage current would not ordinarily be harmful to underground structures in the vicinity of the track.

7. Zinc chloride and other chemical salts used as preservatives render ties highly conducting and greatly increase leakage currents from tracks. Unless combined with some other material, such as creosote, these salts gradually leach out, particularly in damp climates, and eventually their influence on the resistance of roadbeds disappears. Creosote has very little effect upon the resistance of wood ties, but a treating material consisting of 75 per cent gas oil and 25 per cent creosote appears to increase their resistance materially. No direct comparison, however, was made between these two treatments. Open-track construction on which ties treated in this manner were employed had a leakage resistance about twice as great as similar roadbeds with untreated ties and about four times as great as roadbeds with chemically treated ties.

SUGGESTIONS REGARDING ROADBED CONSTRUCTION

Electric railway companies can do much toward reducing leakage currents from their tracks by observing the following suggestions regarding roadbed construction:

1. Solid-concrete ballast should be abandoned, and clean crushed stone should be used as a foundation under ties. This type of construction is approved by the American Electric Railway Asso-

ciation, as it gives greater resiliency to the track and is cheaper than the full concrete ballast.

2. Where crushed stone or gravel is used it should be kept clean by proper coverings or pavements. If earth, sand, or street dirt is permitted to filter into ballast of this character, its function as an insulating material is greatly impaired.

3. Salt, which is often used to prevent frogs and switches from freezing, will greatly reduce the resistance of roadbeds and should be avoided if possible.

4. In open construction rails should be kept out of contact with the earth. The roadbed should be well drained to prevent fine material from washing into the ballast and to keep the ties as dry as possible. Vegetation should be kept down, as this tends to make the roadbed moist and to fill the ballast with foreign material.

5. Zinc chloride and similar chemical preservatives should be avoided where the escape of stray currents is objectionable or where block signals are used. A treating mixture of creosote and gas oil improves the insulating properties of wood ties.

WASHINGTON, January 15, 1919.

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